DOE/NASA/1022-78/33
NASA TM-78922

ENDURANCE TESTING OF FIRST GENERATION (BLOCK I) COMMERCIAL SOLAR CELL MODULES

E. Anagnostou and A. F. Forestieri
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

(NASA-TM-78922) ENDURANCE TESTING OF FIRST GENERATION (BLOCK 1) COMMERCIAL SOLAR CELL MODULES (NASA) 9 p HC A02/MF A01 CSCL 10A

N78-26548

Unclas
G3/44 23348

Work performed for

U.S. DEPARTMENT OF ENERGY
Office of Energy Technology
Division of Solar Energy

TECHNICAL PAPER presented at the
Thirteenth Photovoltaic Specialists Conference
sponsored by the Institute of Electrical and Electronics Engineers
Washington, D.C., June 5-8, 1978

DOE/NASA/1022-78/33
NASA TM-78922

ENDURANCE TESTING OF FIRST GENERATION (BLOCK I) COMMERCIAL SOLAR CELL MODULES

E. Anagnostou and A. F. Forestieri
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Prepared for
U.S. Department of Energy
Office of Energy Technology
Division of Solar Energy
Washington, D.C. 20545
Under Interagency Agreement E(49-26)-1022

Thirteenth Photovoltaic Specialists Conference
sponsored by the Institute of Electrical and Electronics Engineers
Washington, D.C., June 5-8, 1978

ENDURANCE TESTING OF FIRST GENERATION (BLOCK I) COMMERCIAL SOLAR CELL MODULES

E. Anagnostou and A. F. Forestieri

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-9662

ABSTRACT

One phase of the Department of Energy (DOE) Solar Cell Photovoltaic Program is to develop low-cost solar cell arrays with a 20-year lifetime. In order to help determine lifetimes of the first generation (Block I) commercial solar cell modules used in these arrays, a program was initiated by DOE/NASA-Lewis Research Center to expose these modules to a range of environments. Accordingly, Block I modules from four manufacturers were installed at commercial testing sites in Florida, Puerto Rico, and Arizona and at noncommercial sites in Cleveland, Ohio. The conditions endured by these modules encompassed hot and dry, hot and humid, tropical rain forest, sea-air, urban industrial and urban clean. Exposures were for periods up to 1 year. The effect of outdoor exposure on the performance of the modules was determined using current-voltage curves. Short-circuit current (I_{sc}) and maximum power (P_{max}) were the parameters monitored. In order to determine the effect of dirt on performance, some modules were washed periodically and their parameters were recorded both before and after washing. In all cases, there was a loss of performance of the modules with outdoor exposure. The loss was dependent not only on the exposure site but also on the module construction. Three types of modules are covered with silicone pottants and one type has, in addition, a glass cover. This latter type of module had a loss in P_{max} only one-quarter to one-sixth that of the other modules in a comparable period of time. For all modules, some of the performance loss could be recovered by washing. Except for glass-covered modules, where the loss in P_{max} could be completely recovered each time, each succeeding washing recovered loss. Thus, the silicon-covered modules showed a permanent loss in performance. Many modules showed edge delaminations and/or delamination under cells and interconnects. These did not seem to seriously affect power output. It is anticipated that these physical effects will be worse at longer exposure times. Results from these exposure tests indicate that delamination and dirt retention are likely trouble spots in solar cell modules.

INTRODUCTION

The production of electricity from solar energy through the use of solar cells (photovoltaics) has increased largely because of the usefulness of solar cell systems to the space program. To determine whether solar cells could be adapted to terrestrial use and could be a viable source of energy in the future, the Department of Energy (DOE) required information on the lifetime of commercially produced modules. To assist the Jet Propulsion Laboratory (JPL) in the evaluation of these modules, NASA-Lewis Research Center (LeRC) conducted outdoor endurance tests on modules commercially produced as a part of the 46 kW purchase of first generation modules by the JPL Low Cost Silicon Solar Array Project. Modules from four manufacturers were used and these modules are denoted as Block I modules.

Modules were exposed at a variety of test sites with different environments for periods up to 1 year. At some sites, modules were removed periodically and the effect of the environment was determined by the measurement of the electrical characteristics. At other sites, the modules were left undisturbed until the tests were terminated after which time the electrical characteristics were measured. Some modules from each site were washed and remeasured to determine the effects of dirt and other environmental fallout on performance.

This paper presents the results of the testing described above.

MODULE DESCRIPTION AND TEST SITES

A description of the construction of the modules from each manufacturer is given in the following table.

Spectrolab	Aluminum backed; 2 in. diameter cells completely encapsulated in silicone; covered with glass sheet ~1/8 in. thick.
Sensor tech	Aluminum backed; 2 in. diameter cells completely encapsulated in silicone.
Solarex	Fiberglass-epoxy composite backed; 3 in. diameter cells completely encapsulated in silicone.
Solar power	Fiberglass-epoxy composite backed; 3 in. diameter cells completely encapsulated in silicone.

All manufacturers encapsulated the cells in silicone; the Spectrolab module had, in addition, a glass cover.

The sites of the tests are listed below along with a general description of the local exposure conditions:

1. Desert Sunshine Exposure Tests, Inc. (DSET), Phoenix, Arizona. Hot and Dry, desert conditions.

2. Caribbean Testing, Inc., Caguas, Puerto Rico. Tropical, rain forest conditions.

3. Solar Testing Service, Inc., Pompano Beach, Florida. Hot and humid, sub-tropical conditions.

4. Sub-Tropical Testing Service, Miami, Florida. Hot and humid, sub-tropical caonditions.

5. South Florida Testing Service, Miami, Florida. Hot and humid, sub-tropical, sea air atmosphere.

6. Cleveland Air Pollution Control Center (CAPCC), Cleveland, Ohio. A very heavy industrial environment.

7. NASA-Lewis Research Center, Cleveland, Ohio. Ordinary clean urban environment (commercial business and residential areas in prevailing upwind direction).

EXPERIMENTAL PROCEDURE

The effects of outdoor exposure on the modules was determined by the measurement of maximum power P_{max}. This parameter could be obtained by the recording of the current-voltage (I-V) curve of the module. The short-circuit current and open-circuit voltage were also recorded.

The I-V curves were recorded at LeRC using a xenon flash simulator set for air mass one (AM1) conditions and 28° C. The procedure used was as recommended in (1). I-V curves were obtained before the modules were installed at each site and when they were returned to LeRC. For those modules that were on a washing schedule, the I-V curves were recorded before and again after they were washed and dried.

The washing was done using an Alconox-Tide solution and light hand scrubbing until the scrub cloth appeared clean. However, there was no hard rubbing of the module surface. The modules were well rinsed with tap water and then dried. The return schedule and washing schedule for these modules which did not have continuous exposure (Cleveland sites) was determined primarily by local weather conditions.

The modules on test in Florida and Puerto Rico were exposed continuously for one year and then returned to LeRC. I-V traces were recorded and again some modules were washed and P_{max} redetermined. Modules were exposed in Arizona for a total of 161 days before return to LeRC.

The reproducibility of the measurements of P_{max} done on the same day is ±2%. For those done on subsequent days, or by different persons, the reproducibility can be even higher. We have thus assumed that P_{max} differences less than ±2% are not significant.

RESULTS AND DISCUSSION

Modules which are exposed without any intermediate washing were found to accumulate dirt. This can be modified by the effect of precipitation (snow or rain), or condensation and run-off. Figure 1 shows the effect of dirt fallout on the performance of modules exposed at the two Cleveland sites. Several results are immediately evident. First, glass-covered modules (Spectrolab) had the smallest loss in P_{max} and this loss was the same at both sites. Second, for the remaining modules, the losses were very much greater at the Cleveland Air Pollution Control Center (CAPCC). The industrial pollution at this site brought out differences in performance loss among the three silicone-only modules but limited data preclude a ranking. The LeRC data are averages of measurements on two modules of each brand and the CAPCC data are for one module of each brand.

In figure 2, the data from the modules exposed in Arizona, Puerto Rico, and Florida have been superposed on the lines and ranges which encompassed the data from Cleveland. Obviously, the data are more similar to those from the LeRC than CAPCC and again the results for the glass-covered modules are independent of site. The Florida data are averages of measurements from seven modules of each type and those from Arizona and Puerto Rico, of two. A comparison of the Florida and Puerto Rico data shows that the latter site causes more loss in the performance of modules. These modules also showed evidence of mossy growth in many cases.

In order to determine how much of the performance loss could be recovered, some modules were washed, and in some cases reexposed. Losses that remain after washing can be either due to a darkening of the pottant or corrosion of contacts and interconnects or just an inability to remove all of the dirt. Figures 3 and 4 show the results of washing on modules exposed at the Cleveland sites. For the glass-covered modules, washing restored them completely, within experimental error. The silicone-covered modules suffer a permanent loss which increases and then appears to reach a steady state. Comparison of the two figures indicates again that CAPCC is a much harsher site because of a much heavier and more chemically reactive fallout leading to more permanent damage.

The resultant change in P_{max} for the washed modules from Florida, Puerto Rico, and Arizona are compared in figure 5 to the data from Cleveland sites at the termination of the tests. The data are superposed on the curves from figures 3 and 4. The glass-covered modules again show results independent of site. The data for all brands of modules exposed in Arizona and Florida appear similar to the data obtained at LeRC within the experimental error. This is somewhat surprising since the insolation at both of these sites is higher than in Cleveland. This result would indicate factors besides insolation are also important in outdoor exposure testing. Environmental factors such as dirt fallout, including chemically active particulates, can be very damaging, especially in combination with humidity.

Visual observations on the modules indicated delaminations on Solar Power and Solarex modules. In several cases, the delaminations were extensive. However, this did not seem to affect the maximum power of the modules. Glass-covered modules were subject to cover cracking which occurred on several modules due to handling. Again, this did not seem to affect output. It is reasonable to assume, however, that continuing exposure of these cracked modules to more humid environments would eventually cause deterioration in performance.

SUMMARY OF RESULTS

Endurance testing of Block I modules at selected sites has indicated that:

1. For silicone-covered modules made by Solarex, Solar Power and Sensor Tech:

a. Outdoor exposure causes a similar decrease in performance for these brands.

b. The degradation is site dependent with the Cleveland Air Pollution Control Center causing the most degradation because of heavy industrial pollution. Puerto Rico was next because of the tropical rain-forest conditions of its climate.

c. The degradation is apparently not dependent on insolation alone.

d. Washing does not remove all of the degradation. The permanent loss in maximum power reaches a steady value after several hundred days exposure.

2. For glass-covered, silicone potted modules made by Spectrolab:

a. Outdoor exposure is much less damaging than for the other modules tested because of less dirt attraction and retention.

b. Washing the modules recovers the performance loss completely.

3. The effect of local conditions is most damaging where some type of chemical interaction can occur with the module surface as with chemically active particulates and moist mossy growth compared to dry desert sand and field soil.

REFERENCE

1. "Terrestrial Photovoltaic Measurements Procedures," NASA TM-73702, June 1977.

This work was performed for the U. S. Department of Energy under Interagency Agreement E(49-26)-1022.

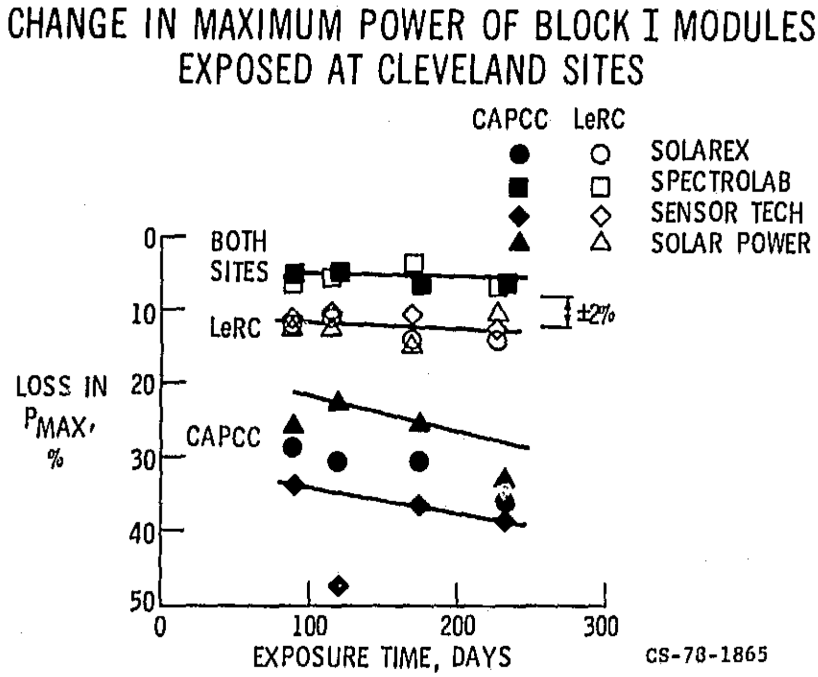

Figure 1.

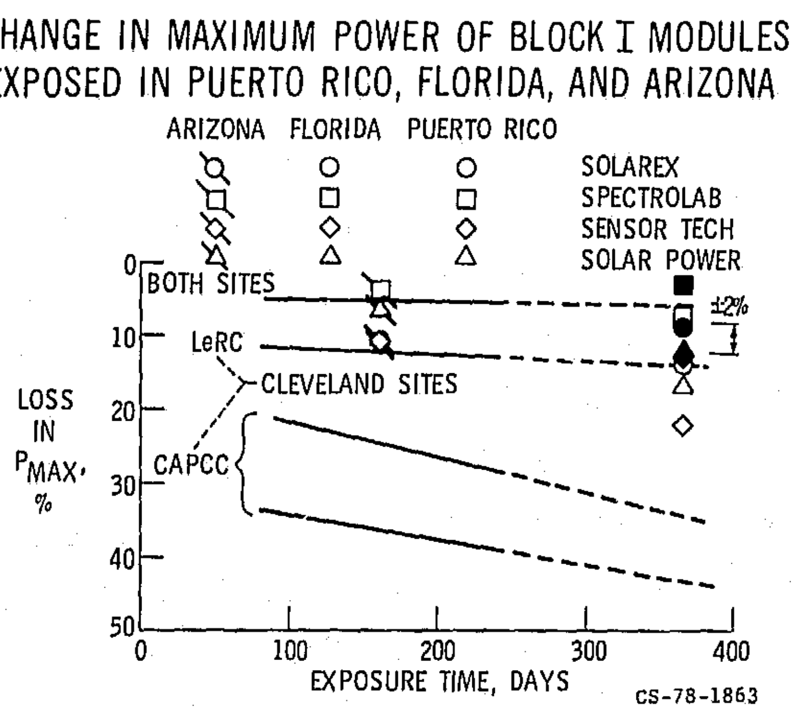

Figure 2.

E-9552

CHANGE IN MAXIMUM POWER OF BLOCK I MODULES
AFTER EXPOSURE AND WASHING

SITE: LeRC

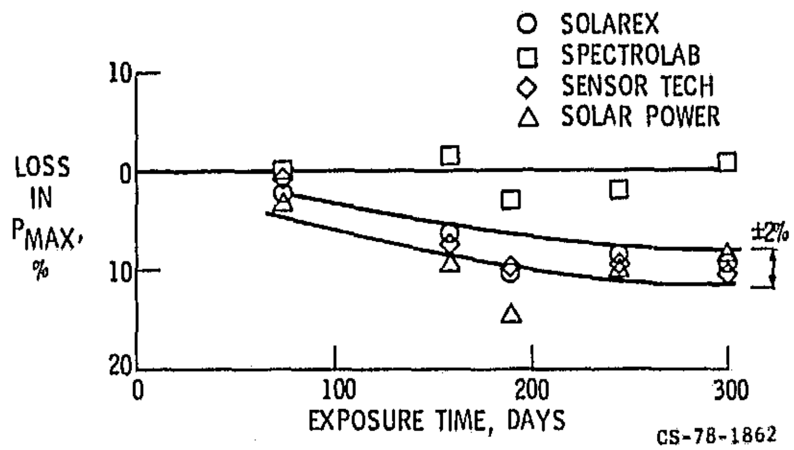

Figure 3.

CHANGE IN MAXIMUM POWER OF BLOCK I MODULES
AFTER EXPOSURE AND WASHING

SITE: CAPCC

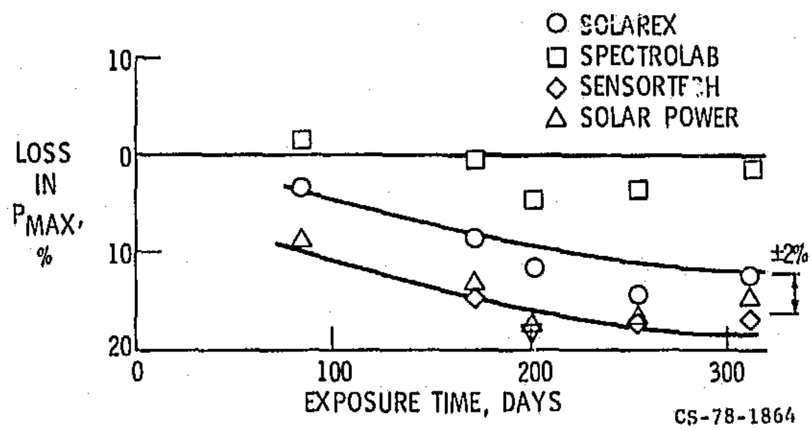

Figure 4.

CHANGE IN MAXIMUM POWER OF BLOCK I MODULES AFTER EXPOSURE AND WASHING

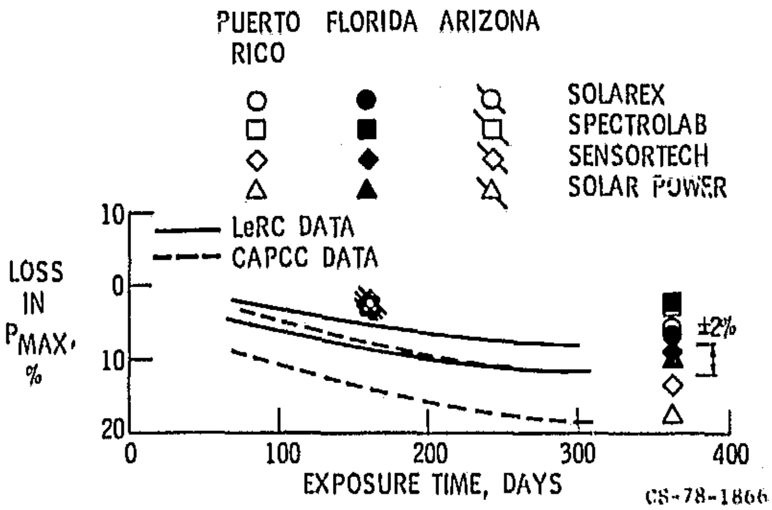

Figure 5.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-78922		
4. Title and Subtitle ENDURANCE TESTING OF FIRST GENERATION (BLOCK I) COMMERCIAL SOLAR CELL MODULES		5. Report Date 6. Performing Organization Code
7. Author(s) E. Anagnostou and A. F. Forestieri		8. Performing Organization Report No. E-9662
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		10. Work Unit No. 11. Contract or Grant No. 13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address U.S. Department of Energy Division of Solar Energy Washington, D.C. 20545		14. Sponsoring Agency Code Report No. DOE/NASA/1022-78/33

15. Supplementary Notes

Prepared under Interagency Agreement E(49-26)-1022. Presented at the Thirteenth Photovoltaic Specialists Conference sponsored by the Institute of Electrical and Electronics Engineers, Washington, D.C., June 5-8, 1978.

16. Abstract

One phase of the Department of Energy (DOE) Solar Cell Photovoltaic Program is to develop low-cost solar cell arrays with a 20-year lifetime. In order to help determine lifetimes of the first generation (Block I) commercial solar cell modules used in these arrays, a program was initiated by DOE/NASA-Lewis Research Center to expose these modules to a range of environments. Accordingly, Block I modules from four manufacturers were installed at commercial testing sites in Florida, Puerto Rico, and Arizona and at noncommercial sites in Cleveland, Ohio. The conditions endured by these modules encompassed hot and dry, hot and humid, tropical rain forest, sea-air, urban industrial and urban clean. Exposures were for periods up to one year. The effect of outdoor exposure on the performance of the modules was determined using current-voltage curves. Short-circuit current (I_{sc}) and maximum power (P_{max}) were the parameters monitored. In order to determine the effect of dirt on performance, some modules were washed periodically and their parameters were recorded both before and after washing. In all cases, there was a loss of performance of the modules with outdoor exposure. The loss was dependent not only on the exposure site but also on the module construction. Three types of modules are covered with silicone pottants and one type has, in addition, a glass cover. This latter type of module had a loss in P_{max} only one-quarter to one-sixth that of the other modules in a comparable period of time. For all modules, some of the performance loss could be recovered by washing. Except for glass-covered modules, where the loss in P_{max} could be completely recovered each time, each succeeding washing recovered less. Thus, the silicone-covered modules showed a permanent loss in performance. Many modules showed edge delaminations and/or delaminations under cells and interconnects. These did not seem to seriously affect power output. It is anticipated that these physical effects will be worse at longer exposure times. Results from these exposure tests indicate that delamination and dirt retention are likely trouble spots in solar cell modules.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
	Unclassified - unlimited STAR Category 44 DOE Category UC-63

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161